Atomic Energy Control Board
P.O. Box 1046
Ottawa, Canada
K1P 5S9

Commission de contrôle de l'énergie atomique
C.P. 1046
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K1P 5S9

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THE MORTALITY EXPERIENCE OF A GROUP OF NEWFOUNDLAND FLUORSPAR MINERS EXPOSED TO Rn PROGENY

by

H. Morrison, R. Semenciw,
Y. Mao and D. Wigle

Health and Welfare Canada
Statistics Canada

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Howard Morrison, Robert Semenciw,
Yang Mao and Donald Wigle

ABSTRACT

A cohort study of the mortality experience (1950-1984) of 1,772 Newfoundland fluorspar miners occupationally exposed to high levels of radon daughters has been conducted using two control groups (surface workers and Newfoundland males). Observed numbers of cancers of the lung, salivary gland and buccal cavity/pharynx were significantly elevated among underground miners. A highly significant relationship was noted between radon daughter exposure and risk of dying of lung cancer; the small numbers of salivary gland (n = 2) and buccal cavity/pharynx cancers (n = 6) precluded meaningful analysis of dose-response. Also significantly elevated among underground miners were deaths from silicosis and pneumoconioses. No statistically significant excess was found for any cause of death among surface workers.

Using external controls, attributable and relative risk coefficients for lung cancer were estimated as 6.3 per working level month per million person-years and 0.89 per cent per working level month respectively. Attributable risk coefficients were similar to some, but not all related mining studies. Relative risk coefficients were highest for those first exposed before age 20. Cigarette smokers had comparable relative and attributable risks to non-smokers. Relative risks fell sharply with age at observation whereas attributable risks were lowest in the youngest and oldest age groups.

Using the risk coefficients from the present study, a miner exposed for 30 years at 4 WLM per year from age 20 has a risk of 7,366 per 100,000 of dying of lung cancer by age 70 using the relative risk model and a risk of 6,371 per 100,000 using the attributable risk model. This compares to 3,740 per 100,000 for a non-exposed male.

RÉSUMÉ

Une étude sur la mortalité (1950-1984) d'une cohorte de 1772 mineurs de spath fluor de Terre-Neuve qui avaient été exposés au travail à des niveaux élevés de produits de filiation du radon a été menée en utilisant deux groupes de référence, les travailleurs en surface et les hommes de Terre-Neuve. Le nombre de cas observés de cancer du poumon, des grandes salivaires, ainsi que de la bouche et du pharynx était plutôt élevé chez les

mineurs souterrains. Une relation très étroite a été notée entre les expositions aux produits de filiation du radon et le risque de mourir du cancer du poumon, tandis que le nombre peu élevé de cas de cancer des grandes salivaires (n = 2) et de cancer de la bouche et du pharynx (n = 6) n'a pas permis d'effectuer une analyse probante de dose-réponse. On a aussi rapporté un nombre plutôt élevé de morts dues à la silicose et à la pneumoconiose. Aucun excès statistiquement notable n'a été observé pour toute cause de mort parmi les travailleurs en surface.

Par comparaison avec les groupes de référence, on a estimé les coefficients de risques attribuables et relatifs de cancer du poumon comme étant 6,3 par unité alpha-mois (WLM) par million d'années-personnes et 0,89 pour 100 par unité alpha-mois, respectivement. Les coefficients de risques attribuables étaient comparables à ceux de certaines études minières sur le sujet. Les coefficients de risques relatifs sont plus élevés pour les personnes qui ont été exposées avant l'âge de 20 ans. Les coefficients de risques attribuables et relatifs des fumeurs de cigarettes sont comparables à ceux des non-fumeurs. Les risques relatifs chutent brusquement à l'âge où le cancer a été diagnostiqué, tandis que les risques attribuables sont le plus bas dans les groupes les plus jeunes et les plus âgés.

Selon les coefficients de risques établis dans la présente étude, un mineur exposé pendant 30 ans à 4 WLM par année depuis l'âge de 20 ans aurait un risque de 7366 sur 100 000 de mourir du cancer du poumon avant l'âge de 70 ans, d'après le modèle de risque relatif, et un risque de 6371 sur 100 000, d'après le modèle de risque attribuable. Par comparaison, on a observé un risque de 3740 sur 100 000 pour les hommes non exposés.

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CHAPTER 1
BACKGROUND

1.1 HEALTH PHYSICS OF RADON "DAUGHTERS"

Radon is a radioactive decay product of radium. As one of the "noble gases", it is chemically inert. Its decay chain begins with uranium-238 and ends with the stable isotope lead-206 (Table 1.1). Of greatest health importance to man are the four immediate decay products or "daughters" of radon 222: Polonium 218, Lead 214, Bismuth 214 and Polonium 214, commonly referred to as RaA, RaB, RaC and RaC' respectively (Ho55).

Radon is ubiquitous in the environment in low concentrations. The levels of radon and its daughter products found in mines and caves can greatly exceed "background" (Ho55). Radon in mines can result from emanations from either the rock face and crushed ore or from radon gas dissolved in underground water. If the source is the rock face or crushed ore, as is usual in uranium and radium mines, radon levels will typically reflect the concentration of radium in both the host rock and in the ores being mined.

High levels of radon in a non-uranium mine are usually the result of ground water contaminated with radon seeping into the mine. Radon is highly soluble in water. At 10 degrees Celsius, 331 cubic centimeters of radon will dissolve in 1000 cc's of water (Wi60). Water in contact with rocks which are relatively low in uranium (less than one part per 100,000) can still become heavily contaminated with radon (Ar60).

The most appropriate measure of the health physics status of air in a mine is the alpha energy which will in the course of time be emitted by short lived radon daughters contained in a given quantity of the air to which the miner is exposed. The unit of measurement normally used is the "working level", defined as any combination of short lived radon daughters in one litre of

air which will result in the ultimate emission of 1.3×10^5 million electron volts (MeV) of alpha particle energy (AS61).

When created, radon daughters acquire a net positive charge due to the loss of electrons during the recoil which follows emission of an alpha particle. In air, these ions quickly become associated with water vapor or other atmospheric constituents to form small charged particles. These tend to attach to larger atmospheric constituents, such as dust particles, or to plate out on nearby surfaces (Wa70). Cigarette smoke can also act as condensation nuclei for radon daughters (Be83).

When air contaminated with radon and its daughter products is breathed into the lungs, radon, because it is a chemically inert gas, is readily exhaled. However, the short lived daughters - polonium, lead and bismuth - may be trapped in the lungs, and deposited on the tracheobronchial epithelium (Ha67).

Deposition of dust particles in the lung is by impingement and diffusion, and varies with the size of the bronchial subdivision and with relative air flow (Li80). Ions and larger particles settle primarily in the upper parts of the bronchial tree, while smaller particles are deposited in the deeper portions of the lung. Unattached ions are almost completely removed in the region above the larynx if breathing is through the nose, but if breathing is through the mouth these ions are likely to be deposited in the trachea and major bronchi (Ha67).

Although there is some movement of deposited radon daughters in the lung, radiation is usually most intense at the sites of greatest deposition. While radon daughters give off alpha, beta and gamma radiation, over 95 percent of the dose to the target cell is from alpha radiation (Sh54).

Most portions of the respiratory system are susceptible to the effects of alpha radiation. In addition to lung cancer, increased risks have also been noted for cancers of the larynx (Ti73) and nasal sinuses (Sc79). Although no excess risk has been reported for cancer of the kidney, this organ receives the second highest radiation dose from radon daughter exposure (Po77).

Alpha particles, because they are high linear energy transfer (LET) radiation, have limited powers of penetration. The alpha particles from RaA and RaC' travel roughly 47 and 71 microns respectively in tissue (Al64). The epithelial tissues of the nose, pharynx and trachea are both thicker and better protected by mucus than is the epithelium of the bronchi (Wa70). As a result, they are probably less susceptible to the effects of alpha radiation. The mucous sheath in the critical region of the segmental and sub-segmental bronchi is estimated to be roughly 20 microns in thickness, while the distance from the mucous layer to the critical region of the basal cells is estimated at 36 microns (Wa70; Ax78).

Factors such as cigarette smoking which affect the thickness of the mucous layer may be of considerable importance in alpha radiation induced lung cancer (Ax78; St83). It is also possible for radon daughters to be absorbed into body fluids or be translocated through ciliary action and then swallowed into the gastro-intestinal tract.

1.2 STUDIES OF MINING POPULATIONS EXPOSED TO RADON "DAUGHTERS"

The earliest recorded observations concerning the biological effects of radon daughter were made in the sixteenth century by Agricola in the Erz mountains of Bohemia (Th82). Agricola noted that the silver miners of Joachimsthal (Jachymov) suffered from a disease called Bergkrankheit or "mountain disease". In 1879, Harting and Hesse demonstrated that a similar disease among

pitchblende miners in Schneeberg in nearby Saxony was the result of malignant tumours of the lung. Arnstein (Ar13) reported that forty-four percent of miners in Schneeberg, Saxony died of lung cancer. Similar findings were reported by Peller (Pe39) concerning the Joachimsthal miners.

In the 1950's there was a large increase in the demand for uranium, both for the construction of nuclear weapons and for the production of electricity (Th82). As a consequence, uranium mining greatly expanded, most notably in the Colorado Plateau region of western United States, Czechoslovakia, in Ontario and in Saskatchewan. These four uranium mining populations, in addition to hard rock miners in Sweden and fluorspar miners in Newfoundland comprise the main cohorts of men, occupationally exposed to radon and its daughter products which have been studied to date.

1.3 HISTORY OF FLUORSPAR MINING IN ST. LAWRENCE NEWFOUNDLAND

Fluorspar (fluorite, calcium fluoride, CaF_2) is used in the electrolytic stage of aluminum smelting. It is also used in the making of steel and as a source of fluorine in the manufacture of such chemicals as hydrogen fluoride and various fluorinated hydrocarbons. In its pure state it is colourless, but in its more common impure state its colour is usually green or blue (Ne68).

In a survey of the south coast of Newfoundland in 1765, Captain James Cook noted a "blue beach" in St. Lawrence harbour, which presumably was an outcropping of fluorspar. Geological surveys in 1843 and 1870 confirmed the existence of fluorspar in the area.

In St. Lawrence, fluorspar occurs as epithermal veins filling fault-fissures, chiefly in granite. These veins, generally between 70 and 90 degrees are from less then 25 millimeters to

more than 15 meters wide. Higher-grade veins are usually narrow with an average width of 1.2 to 1.5 meters, an average fluorite content of 90 percent and an average silica content of 5 to 6 percent. Lower grade veins have an average width of 4.5 to 6 meters, an average fluorite content of 60 to 70 percent and an average silica content of 15 to 20 percent. East-west veins tended to be of the narrower, higher fluorite variety, while north-south veins tended to be wider, with a lower fluorite concentration (Ne68).

The first indication that the St. Lawrence fluorspar deposits might be of economic importance was in 1912, when Mr. J. Campbell, a St. John's butcher, staked leases on several claims (Newfoundland Fluorspar Limited, 1968). Interest in mining fluorspar in St. Lawrence increased throughout the 1920's. Stakes were claimed in 1928 for the Black Duck vein by Mr. W.H. Taylor, who also bought Campbell's claims. Taylor later sold these to Mr. Walter E. Seibert, who began the St. Lawrence Corporation of Newfoundland Limited in 1933 to mine fluorspar. A competing company, the American Newfoundland Fluorspar Limited was established in 1936. It was sold in 1940 to the Aluminum Company of Canada (Alcan) and renamed the Newfoundland Fluorspar Limited (Newfluor).

Mining was initially by open cut methods. Operations were converted to standard underground mining procedures in 1936. Because mining was started in the middle of the depression, work was done with antiquated equipment. For example, initial shafts were sunk with hand steels. Wages as well as health and safety conditions were very poor during the first decade of operations.

It was not until 1941 that the St. Lawrence Workers Protective Union was formed. The strikes which followed resulted in union recognition, higher wages and improved working conditions. Until 1942 drilling used dry jackhammers, which

resulted in large amounts of dust. Even after the introduction of wet drilling many men did not use the water, because it would pour up their sleeves while they drilled. Many miners erroneously believed that the water was to keep the drill from melting and did not understand the health implications.

Other improvements introduced at this time included mucking machines and electric trammers. Probably the most significant improvement from the point of view of radon daughter concentrations was the change to two instead of three shifts daily. This allowed blasting gases and dust to be cleared using compressed air during the four hours between shifts. Otherwise ventilation was by natural draft, occasionally supplemented by small blowers. The amount of ventilation varied greatly between and within given mines over time according to the introduction of compressed air and the sinking of new shafts and raises.

The mines were inspected annually by inspectors brought in by the Newfoundland government. However it was not until 1951 that mining regulations were introduced. Most improvements were the result of persuasion by the inspectors and from strikes held by the miners (RC69).

Almost all mines in the St. Lawrence area were very wet. Amounts of water pumped from mines varied from less than 10 liters per second at Hares Ear to over 50 for Iron Springs (RC69; Co84).

Although over 40 fluorspar veins have been located in the St. Lawrence area, most of the ore produced came from only two mines - Iron Springs and Director (RC69). These were mined respectively by the St. Lawrence Corporation and the Newfoundland Fluorspar Corporation.

Iron Springs was an East-West vein mined to a width of up to 1.5 meters. Mining was by stope shrinkage at the 18, 30, 54, 72, 102, 135, 168, 201, 237 and 267 meter levels (Co84). Ventilation was substandard at Iron Springs, which had only a single small raise to the surface, 185 meters from the main shaft. A five horsepower blower was introduced for a few months one year in the early 1950's, but when it broke down, it was never repaired or replaced. Iron Springs is believed to have had the worst ventilation of any of the mines in the St. Lawrence area. It was closed in 1956 as a result of the St.Lawrence corporation's loss of important American contracts and was allowed to flood (RC69; Co84).

The Director mine in contrast had, from 1955 onward, some forced air ventilation at the 250 meter level. Director used a cut and fill method of mining in contrast to the shrinkage method used in Iron Springs. The result was that Director had multiple raises to the surface and between levels, which greatly increased ventilation. Both mines were, however, extremely wet.

In the early 1950's large numbers of cases of pneumoconiosis were diagnosed among the fluorspar miners (de64). In addition, there had been a number of cases of lung cancer in the community apparently restricted to the mining population. At this time there was no indication of radiation in the mines. Measurements of gamma radiation, made for other purposes in 1952 or 1953, gave no indication of radiation (RC69). As a result of concerns regarding the safety of the mines, the Department of National Health and Welfare sent J. P. Windish in 1956 and 1957 to test for possible causative agents. Silica and fluoride dust concentrations were tested and found, in general, to be below permissible levels (Wi58).

It was not until 1959 that tests were made for the existence of radiation in the mines. At that time Windish (Wi60) and the

A.D. Little Company (Ar60) documented high levels of radiation from radon and its daughter products in the Director mine. Eighty radon daughter samples were taken at 50 different underground locations. Values ranged between 0.4 and 193 working levels (WL) in unventilated areas and from below the level of detection to 12 WL in ventilated portions of the mine.

Measurements taken in the crushing and heavy medium separation plants on the surface revealed values varying from below detectable levels to 0.48 WL. In the shaft bin on the surface, values ranged between 0.89 and 1.6 WL. Radon concentrations were measured in 17 underground locations in the Director mine. In dead-end unventilated areas, concentrations ranged between 270 pCi per litre and 13,300 pCi per litre (2.7 to 133 WL). External gamma radiation values were below the existing standard of 2.5 mR per hour. Gamma radiation was measured from film badges worn by mining personnel or placed in the mine.

The source of the radon and its daughter products was eventually identified as the water which constantly poured into the mines. Levels of radon in the mine water varied from 12,000 to 13,000 pCi/litre. Levels in the town drinking water were comparable at 9,000 to 15,000 pCi/litre. Although water was not sampled from all mines worked, it was assumed that levels would be comparable to those found in Director and Hares Ear mines. The level of uranium in the host granite was measured at 110 parts per million (Ar60). In 1960, as a result of the high levels of radon found, mechanical ventilation was introduced into all levels of all mines still operating and radon daughter levels fell well below 1 working level (WL). The last mine, Director, closed in 1978.

1.4 PREVIOUS STUDIES OF THE ST. LAWRENCE FLUORSPAR MINERS

The first published report examining the mortality experience of the fluorspar miners in St. Lawrence was by de Villiers and Windish in 1964 (de64). They calculated age-specific standardized mortality ratios (SMRs) for fluorspar miners using mortality rates for the Burin Peninsula minus St. Lawrence to generate expected values. Numbers of deaths from various causes were compared between St. Lawrence and a control town, Grand Bank. Mean latency for lung cancer was calculated by plotting age at first exposure by age at death. De Villiers and Windish found that the number of lung cancer deaths among fluorspar-miners was far in excess of expected, with SMRs varying from 7.9 to 43.2, depending on the age group.

A second paper, by Parsons et al (Pa64), examined the prevalence of respiratory symptoms among miners and concluded that levels of pneumoconiosis and bronchitis were comparable to those reported among other groups of hard rock miners. The role of cigarette smoking in the induction of lung cancer among fluorspar miners was addressed, with the conclusion that, although smoking was a contributing factor in the very high levels of lung cancer noted among the miners, most of the excess was radiation related.

The first attempt to examine the dose - response relationship was in a paper published in 1971 by de Villiers and colleagues (de71). The number of hours worked underground was used as a surrogate for actual exposure in WLMs. A plot of lung cancer deaths by number of hours worked revealed an exponential relationship. In order to adjust for the variable radiation exposure of differing occupations, hours were weighted according to occupation. Drifters and stope workers were assigned a radiation level of 8 WLs, muckers, trammers, and chute operators were assigned a level of 4 WL and shaftmen were assigned a level

of 2 WL. With the assignment of these weights, the dose - response relationship became linear.

In 1977, Wright and Couves published a paper (Wr77) which was restricted to examining the histology and survival rates of lung cancer cases among the miners. Although miners tended to reject surgery for treatment because of a mistaken belief that exposure of cancer to air accelerated its growth, mean survival time was not shortened.

In 1981, an update of the 1971 paper by de Villiers et al. was published (Mo81) which extended the mortality follow-up to 1978. Estimates of radon daughter levels were based on those used in the 1971 paper. These estimates were based on occupation and hours worked only. Mine site and annual exposure data were not used.

In 1985, a further update was published which extended the follow-up period to 1981 (Mo85). This analysis, like previous ones, used the modified person-years approach. Expected numbers of deaths were generated from an internal control group of surface workers unexposed to radiation. Unlike previous analyses, cigarette smoking and latency were taken into account. In addition, excess risks were estimated.

TABLE 1.1

THE URANIUM SERIES

NUCLIDE	HALF-LIFE	MODE OF DECAY (MAXIMUM ENERGY, MEV)
U-238	4.5×10^9 years	alpha (4.3)
Th-234	24 days	beta (0.3)
Pa-234	1.2 months	beta (2.3)
U-234	2.5×10^5 years	alpha (4.9)
Th-230	8×10^4 years	alpha (4.8)
Ra-226	1620 years	alpha (4.8)
Rn-222 (Radon)	3.8 days	alpha (5.6)
Po-218 (RaA)	3 minutes	alpha (6.1)
Pb-214 (RaB)	27 minutes	beta (1.0)
Bi-214 (RaC)	20 minutes	beta (3.3) + gamma
Po-214 (RaC')	1.6×10^{-6} seconds	alpha (7.7)
Pb-210 (RaD)	22 years	beta (0.06)
Bi-210 (RaE)	5 days	beta (1.2)
Po-210 (RaF)	138 days	alpha (5.3)
Pb-206 (RaG)	stable	- - - -

MeV = million electron volts

CHAPTER 2
MATERIALS AND METHODS

The study cohort consisted of 1,772 miners and 352 millers and surface workers employed by either the St. Lawrence Fluorspar Company or by the Newfoundland Fluorspar Limited. Mortality from 1933 to 1984 and from 1950 to 1984 was analysed using a modified life-table technique with both an internal and an external control group.

Prior to analysis, it was necessary to merge various data files so as to create for each miner the following: a set of unique personal identifying information, a year-by-year estimate of radiation exposure in working level months, an estimate of cigarette smoking status, and, when appropriate, cause and date of death.

2.1 DATA SETS

There were five main data components to the working file. They were: personal identifying information, occupational histories, smoking histories, death data and working level estimates of mines by year and occupational category. These were found on ten files - six largely composed of work histories (files A-F), a Social Insurance Number (SIN) file, a death file, a smoking history file, and a file containing conversion tables for estimating working levels according to year, mine site and occupation. The first five of these files were already in existence at the beginning of the present analysis; the remaining five had to be assembled.

2.11 PERSONAL IDENTIFYING INFORMATION

Personal identifying information was available from all files with varying degrees of completeness. Miners' names were available on all files. Complete date of birth (day, month, year) was potentially available on six files: B-C, D, F, death,

SIN and smoking. Mother's maiden name was available from the SIN file, while place of birth was sometimes present on file F.

2.12 OCCUPATIONAL HISTORIES

When the latest phase of this project was initiated in 1981, there were five data files containing either occupational histories or radiation estimates: files A, B-C, D, E and E-updates. A further file, named F, was created in 1982. A brief description of the files follows. A more detailed description is in Appendix A.

File A was assembled by the Newfoundland Government. It consisted of personal identifiers and estimates of both cumulative pre-1960 and year - by - year 1960+ radiation exposures. In general, this file proved to have little use; pre-1960 exposures were assumed in all cases to be equal to 13.0 WLs. File B-C was a combination file produced by the Atomic Energy Control Board (AECB) from a survey conducted in 1978 and contains personal identifiers, social insurance numbers, smoking and mining histories as well as date of death, if available. This file was useful only for its' cigarette smoking histories; work histories were based on the recall of miners and their next of kin.

File D was assembled by the Department of National Health and Welfare. It contained personal identifying information as well as detailed occupational histories. This was a very useful file in that it contained information not available on other files such as place of work. File E was also assembled by the Department of National Health and Welfare. It contained the largest number of miners, but its occupational histories were much cruder then those found on file D. Work histories covered the period from 1933 to 1967. File E-updates was a continuation of file E which gave radiation exposure estimates for the years 1968 and 1969 in working level months.

File F was assembled by the Department of National Health and Welfare from copies of work histories obtained from the Aluminum Company of Canada Limited. It contained detailed personal identifying information not available on other files such as place of birth, as well as occupational histories.

2.13 SMOKING HISTORIES

Smoking information was available for many miners as a result of four surveys, conducted in 1960, 1966, 1970 and 1978, and compiled into a smoking history file. The first three surveys were conducted by Dr. A. de Villiers of the Department of National Health and Welfare. Data from these surveys had not been used in previous analyses of this cohort. Prior to its use, it was necessary to code, keypunch and verify the data from the original documents. The most recent survey was conducted by the Atomic Energy Control Board. Results from this survey were in file B-C. All of the surveys queried current and previous smoking habits. Using the above sources, it was possible to estimate smoking habits for 48.2 percent of the underground miners and 10.3 percent of the surface workers. Details concerning the creation of smoking histories are found in Appendix B.

2.14 DEATH DATA

Death information on miners was obtained through manual record linkage to death records contained in the national mortality database operated by Statistics Canada. The small cohort size rendered it impractical as well as overly expensive to use the computerized record linkage system operated by Statistics Canada. In addition to the usual variables such as date of birth and name, record linkage relied heavily upon any mention of a Newfoundland connection; almost all of the miners were local men, most of whom appeared to have remained in the Burin Peninsula of Newfoundland.

The linkage, performed by Statistics Canada employees who were "blind" as to exposure status, consisted of comparing personal identifying information on workers (name, date of birth, occupation, place of death) with microfiched data on all Canadian deaths from 1926 to 1984. Copies of microfilmed death certificates were obtained and underlying causes of death coded to the 8th revision of the International Classification of Diseases by the Nosology Reference Centre of Statistics Canada. Persons not found were assumed to be alive for the purposes of analysis.

In addition to underlying and contributing causes of death, date of death and date of birth were also retrieved. This information was then keypunched and verified. The causes of death studied and their corresponding ICD rubrics are listed in Appendix C.

2.15 YEAR-MINE-OCCUPATION-SPECIFIC WORKING LEVEL MONTH ESTIMATES

Working level month estimates according to year, mine and occupation for the period 1933 to 1960 were provided by the Atomic Energy Control Board of Canada (Co84) and were based on known values from the Director mine prior to the introduction of ventilation. They reflect what is known of the histories of the various mines as well as the likely exposure resulting from different occupations. Details regarding the use of these estimates are found in Appendix D. From 1961 onward, exposure measurements for individual miners were available.

2.2 CREATION OF A UNIFIED WORK HISTORY FILE

In order to create a unified work history file, the following major steps were undertaken. A more detailed description is found in Appendices E through G.

1. Mine site was coded and added to file D.

2. A unique miner identification number was added to all records.
3. Duplicate work histories were removed.
4. Occupational histories were merged.
5. Coding schemes were simplified.
6. Occupations were classified according to probable radiation exposure.
7. A table was created in order to convert hours worked by year, occupation and mine site into estimated radiation exposure by WLMs and records were so converted.
8. Personal identifying information was merged.
9. Smoking histories were standardized and merged.
10. Smoking variables were created.
11. The mortality database was searched and deaths coded and keypunched.
12. The files containing information on individual radiation exposures, smoking histories, personal identifying information and death data were merged.
13. The working history file was edited and the data therein validated.

2.3 CREATION OF THE WORKING FILE

At this stage, the three files containing information on radiation exposure, personal identifier and smoking histories and death information were brought together. Five hundred and thirty-seven miners and surface workers who lacked birth data and/or work histories were dropped (339 underground and 198 surface). This reduced the number of fluorspar workers studied from 2,661 to 2,124. The three files were matched by the six digit miner ID number. The variables "age started working", "age first exposed", "age last exposed" and "age last worked" were calculated.

2.4 CREATION OF THE ANALYTICAL FILE

A computer program was written to produce a series of tables giving person-years (PYs) and deaths by specified categories. The input file consisted of year-by-year WLM estimates, complete

with additional variables such as year of birth, smoking status and cause of death (if any). The program was written to "age" each miner from the time of his entry into the study (year first worked) until the end of the study (1984) or until his death. In doing so the program assigned each individual's PYs to different categories as he was "aged". Six variables were used, creating 326,592 possible categories for PYs.

For example, one could take a simple case in which only two variables are considered - calender year and age. A miner born in 1900 is first employed in 1940. He would move diagonally through a 2 x 2 matrix defined by age and calendar year, accumulating PYs and changing categories as he does. From 1940-1944, his PYs would accumulate in the 1940-1944, age 40-44 category. From 1945 to 1949, his PYs would accumulate in a different category, the 1945-1949, age 45 to 49 category.

A year in which a death occurred was counted as a half year. If this hypothetical miner had died in 1947, he would have only accumulated 2.5 PYs in the 1945-1949, age 45-49 category.

Because lung cancer is believed to have a minimum latency of at least 10 years from the onset of exposure, the program was written to exclude PYs and deaths according to six different latency categories («10, «15, «20, «25, «30 and «35 years). In order to increase comparability, and because lung cancer is believed to have a latency of at least 10 years after first exposure, most of the dose-response and all of the excess risk analyses excluded deaths and PYs during the first ten years after underground exposure. Dose-response analyses in which no adjustment was made for latency and in which an adjustment was made for a twenty year latency period were performed in order to assess the effect of removing the first ten years of PYs and deaths after first exposure.

Smoking status and age at first exposure were fixed from the beginning of the analysis for each miner. Age was classified by five year age groups, beginning at 10 to 14 years, with the last category being 85 years and older. Calendar year was classified by five year intervals, except for the first category. The first category selected was 1933-1939, and the last category was 1980-1984. Smoking status was analysed using five categories (non-smoker, ex-smoker, light smoker, heavy smoker and unknown). Further details regarding the definitions of each of these categories are found in Appendix B.

The variable "age at first exposure" was composed of an unexposed category and seven exposed categories, beginning with less than 20 years and ending with 45 years and over. Latency was composed of an unexposed category, a less than 10 year category and then by five year increments, five further categories, ending with a less than 35 year category. Dose was analysed using only seven categories, although 13 were available. This was done in order to reduce the number of strata. WLM categories were chosen prior to examining the risk estimates and were based on increments of one hundred WLMs.

2.5 PERSON-YEARS ANALYSIS

Analyzing the fluorspar cohort using the PYs method involved allocating each miner's and surface worker's follow-up time to one of several mutually exclusive and exhaustive categories determined by his status with respect to age, calendar period, cumulative radiation exposure and smoking status. Deaths were assigned to only one category according to the decedent's status at the time of death. An exception to this was smoking status. As a decedent's smoking status was unknown at the time of death, his status was taken as recorded on the most recent smoking survey to which the miner had responded.

In order to calculate "expected" numbers of deaths among miners, two methods were used: one using an internal control group of unexposed surface workers and one using Newfoundland males as an external control population. In both cases, the total PYs in each stratum were multiplied by the corresponding stratum - and disease - specific mortality rate in the control population and then summed over strata to obtain the number of "expected" deaths for comparison with the observed number of deaths.

Statistical significance of SMRs using internal controls was assessed using the Peto-Pike chi-square test (Pe73; Sh76). When an external control group was used, a one-sided p-value was obtained from a Poisson distribution with mean equal to the expected (Ba64).

The analysis based on an external control group used Newfoundland male mortality rates from 1950 to 1984 to generate expected numbers of deaths. No age, period, cause - specific mortality rates for Newfoundland were available prior to 1950. As a result, PYs and deaths from 1933 to 1949 were excluded.

The analysis using surface workers as a control group examined lung and gastro-intestinal cancer mortality only. The small numbers of deaths and PYs among surface workers meant it was inappropriate to examine all but the most common causes of death. For some causes of death such as pneumoconiosis, all cases occurred among the exposed group.

Two different computer programs were used to analyse fluorspar miner mortality. Both programs produced rates and standardized mortality ratios. The main difference was the ability of one program to handle many causes of death at the same time and of the other to examine dose-response relationships. One was based on a program developed by Richard

Monson (Mo74). This program was not capable of varying dose categories of miners over time. Accordingly, workers were first stratified by mining status (surface or underground) prior to analyses using this program. The end results of this program were SMRs calculated for surface and underground workers separately for the period 1950 to 1984. The second computer program was capable of handling changes in dose categories over time, and was used to assess dose-response relationships (Se86).

Tests for trend (Ar55) were performed for cancers of the lung, stomach, digestive tract and buccal cavity/pharynx using person-years as weights.

2.6 MODEL FITTING

Modelling was used in order to assess the nature of the lung cancer dose-response relationship and to estimate attributable and additive relative risk coefficients using the external control group only. The curve-fitting method used was an iterative, weighted least-squares procedure (La80; Kn79) using the SAS routine NLIN (SA85), with the inverse of the variances as weights (Th82). Models were reparameterized to avoid skewness (Br88; Th81).

Attributable risks were calculated as the difference between observed and expected deaths divided by person-years, while relative risks were calculated as the ratio of observed to expected deaths. With the exception of the model used to examine risk by cigarette smoking status in which a constant term was added, the relative risk of unexposed persons was assumed to be 1.0 and the attributable risk to be 0. Risk coefficients by age at first exposure were based on an analysis which included unexposed workers restricted by age. Chi-square tests for lack of fit and improvement in fit were performed for relative and attributable risk models (Th82).

Two different classes of models were used to estimate attributable and relative risk coefficients. In those used to examine risk by cumulative dose, age at observation and age at first exposure, the relative risk of unexposed persons was assumed to be 1.0 and the attributable risk to be 0. The relative risk model used was $RR = 1+e^{\beta}$ Dose, and the attributable risk model, $AR = e^{\beta}$ Dose. In the models constructed to examine risk by cigarette smoking status, the assumption regarding no increased risk to persons unexposed to radiation could not be made. Accordingly, constant terms were added to the models. The relative risk model used was $RR = \beta_0 (1 + e^{\beta_1}$ Dose) and the attributable risk model was $AR = \beta_0 + e^{\beta_1}$Dose.

CHAPTER 3
LUNG CANCER

3.1 CIGARETTE SMOKING

The cigarette smoking status of workers was determined through 4 surveys, conducted in 1960, 1966, 1970 and 1978. Smoking status was known for 48% of underground miners and 10% of surface workers. As displayed in Table 3.1, smoking status was comparable between surface and underground miners of known status. Among the 854 underground workers of known smoking status, only 13 per cent (118) never smoked, while 70 per cent (599) were current smokers as of the date of last interview. The prevalence of smoking among those of known smoking status was constant across dose categories.

3.2 INDUCTION-LATENCY

Induction-latency is the length of time between first exposure to a carcinogen, in this case alpha radiation, and diagnosis (or death) from the cancer of interest. Lung cancer mean latency by age at first exposure and cigarette smoking status is summarized in Table 3.2. The overall latency was found to be 26.0 years. The length of latency decreased from 30.6 years for those first exposed from age 15 to 19 to 19.0 years for those first exposed from age forty onward. The latency periods of smokers were longer than those of non-smokers; however, the differences were not statistically significant. Mean latency was found to be 17.1 years for those who had never smoked compared with 27.5 years for those who had ever smoked.

The length of the induction-latency period was found to be inversely related to age at first exposure. This is in agreement with previously reported findings for the Colorado Plateau miners (Ar81). The induction-latent period was not significantly different for smokers than for non-smokers. Other studies examining this issue have found smokers to have shorter induction-latency periods than have non-smokers (Ax78; Ar81).

3.3 DOSE-RESPONSE RELATIONSHIP

This study examines the mortality experience of 2,124 miners, millers and surface workers from January 1, 1950 to December 31, 1984, employed during the period from January 1, 1933 to December 31, 1978. A total of 445 deaths were recorded among underground miners, of which 113 were from lung cancer.

The risk of death due to lung cancer as a function of lifetime cumulative radiation exposure using internal controls is presented in Table 3.3. Lung cancer mortality was elevated for every exposure category, although statistical significance was not reached until the 400 WLM or more category. Using external control, statistical significance was reached in the lowest exposure category (Table 3.4). In the highest dose category (2,500+ WLM), the ratio of observed to expected number of deaths was over thirty. The test for trend was highly significant ($p < 0.001$).

Table 3.5 displays the number of observed and expected lung cancer deaths according to length of time since first exposure to radiation. No significant increase was noted for the first ten years after first exposure. Some fall-off in SMRs was noted with increasing time since first exposure after the initial latency period. Standardized mortality ratios were found to decline with time since last exposure (Table 3.6), with a larger proportional decline noted with increasing cumulative dose.

The present study confirms the strong association which exists between exposure to radon and its daughter products and the risk of dying of lung cancer. Even though 20 per cent of the cohort as originally defined had to be excluded, it is not believed that this introduced any bias into the findings. The disease status of excluded men did not influence their exclusion as they tended to be young short term employees who were at low risk of lung cancer during the period that they were under

observation. Comparison of lung cancer mortality risks among unexposed cohort members and non-cancer mortality among exposed cohort members with the general population of Newfoundland (SMRs = 0.90 and 0.91 respectively) gave evidence of reasonable follow-up.

No lung cancer cases were noted within the first five years after underground exposure. During the next five year period, a non- significant excess in lung cancer mortality was noted (SMR = 3.48). This is similar to data reported for the Saskatchewan uranium miner cohort which noted a significant increase in the five to nine years after first exposure (Ho86), but in contrast to the Swedish iron miner cohort which found no significant excess until 20 or more years after first exposed underground (Ra84). One criticism which has been made against earlier analyses of the fluorspar cohort was that there was no adjustment made for latency (Th82). The rationale for adjusting for latency is to remove lung cancers which were not radiation induced as well as PYs during which a miner was not actually at risk of dying of radiation - induced lung cancer.

3.4 LUNG CANCER MORTALITY: ATTRIBUTABLE AND RELATIVE RISK

Figures 3.1 and 3.2 display the results of linear regression analysis of the relationship between lung cancer risk and radiation exposure. A simple linear model gave a relatively poor fit to the data, but could not be rejected (chi-square lack of fit attributable risk model = 5.7, 5 df, $p \gg 0.25$, relative risk model = 7.7, 5 df, $p \gg 0.05$). The addition of a quadratic term failed to significantly improve the fit of the model (chi-square improvement in fit attributable risk model = 3.3, 1 df, $p \gg 0.05$, relative risk model = 2.5, 1 df, $p \gg 0.10$). Attributable and relative risk coefficients were estimated as 6.3 per working level month per million person-years and 0.89 per cent per working level month respectively.

3.41 ATTRIBUTABLE AND RELATIVE RISK BY AGE AT FIRST EXPOSURE

To explore the effect, if any, of age at first exposure on risk of dying of lung cancer, attributable and relative risk coefficients were calculated by age at first exposure (Table 3.7). Attributable risk coefficients increased with age at first exposure. Relative risk coefficients were highest for the youngest age at first exposure category (age 15-19); thereafter, the relative risk coefficients were relatively constant. However, addition of a term for age at first exposure did not significantly improve the fit of the attributable risk (chi-square improvement in fit = 2.12, 1 df, $p \gg 0.05$) or relative risk (chi-square improvement in fit = 2.21, 1 df, $p \gg 0.05$) models.

3.42 ATTRIBUTABLE AND RELATIVE RISK BY AGE AT OBSERVATION

Relative and attributable risk coefficients by age at observation are presented in Table 3.8. Relative risk coefficients fell with increasing age during follow-up, whereas attributable risk coefficients increased until the second oldest age group. The addition of age at observation significantly improved the fit of both the attributable risk (chi-square improvement in fit = 5.80, 1 df, $p \ll 0.05$) and relative risk (chi-square improvement in fit = 63.33, 1 df, $p \ll 0.01$) models.

3.43 ATTRIBUTABLE AND RELATIVE RISK BY SMOKING STATUS

Relative and excess risk calculations according to smoking status are given in Table 3.9. Attributable and relative risk coefficients were comparable for ex-smokers, current smokers, never-smokers and those of unknown smoking status.

3.44 RELATIVE AND ATTRIBUTABLE RISK COMPARISONS WITH OTHER STUDIES

Assuming a linear model the attributable risk coefficient was estimated at 6.3 per million person-years per WLM. This is considerably lower than an earlier estimate using this cohort;

the National Research Council (BEIR III) report (NR80) estimated an attributable risk coefficient of 18 per million PYs per WLM. This discrepancy is likely almost entirely the result of the new dose estimates used in the present analysis. The present estimate is in close agreement with the Colorado Plateau miners study (6 per WLM per million PYs) and the Ontario uranium miners study (5.9 per WLM per million PYs). It is, however, much lower than values estimated from the most recent analysis of Swedish metal miners by Ra84) and those of the Czechoslovakian (NR80) and Saskatchewan uranium miners studies (Ho86). Attributable risk coefficient estimates tend to be either around 6 or 20 per million PYs per WLM. The relative risk coefficient estimated from the present study (0.9% per working level month) is lower than those estimated from the Swedish iron ore study of 3.6% per working level month (Ra84) and the Saskatchewan uranium miner study of 3.3% per working level month (Ho86).

One possible explanation for the differences in risk estimates is that the dose rate is an important variable. The two populations with the highest dose rates (the present cohort and the Colorado Plateau cohort) also had the lowest risk per unit of cumulative exposure. It may be that higher dose rates lead to less risk per unit dose (NR80). Evidence of this is found in the survival analyses of the Colorado Plateau miners cohort. Hornung (Ho81) and Whittemore & McMillan (Wh83) both found that lower dose rates were more damaging per unit of exposure than higher dose rates. This finding was also reported by Kunz et al in Czechoslovakian miners (Ku79). This concept is biologically plausible. At high dose rates, alpha radiation may be less effective in inducing cancer because there is an increased probability that multiple "hits" will kill cells. Many mathematical models of carcinogenesis include a cell-killing term (Th82).

However, dose rates for the Ontario miners cohort were relatively low and yet the estimated attributable risk is comparable to those of the present study and the Colorado Plateau study. One explanation may be the relatively short follow-up period of the Ontario uranium miners study. Studies with long follow-up periods such as the Swedish iron ore study by Radford and colleagues (Ra84) tend to report higher excess risks.

The most likely explanation is that many of the differences result from inaccuracies in the dose estimates. Uncertainties in exposure estimates are inherent in the nature of occupational epidemiology. Regulatory agencies or mining companies are unlikely to monitor a factor which is not believed to be present in the mines or one which is not believed to be harmful at the levels detected if known to be present. Certainly each of the radiation mining studies has had to estimate personal exposures to radon daughters for at least part of the follow-up time.

Although attributable risk coefficients increased by age at first exposure, the addition of age at first exposure did not significantly improve the fit of the attributable risk model. The Swedish iron and Colorado plateau uranium miners studies (Ra84; Wa81) both reported no difference in risk according to age at first exposure, unlike the Saskatchewan and Czechoslovakian studies (Ku79; Ho86) which both reported increasing attributable risk coefficients with increasing age at first exposure.

Relative and attributable risk coefficients were found to be comparable for smokers and non-smokers, with a slightly higher attributable risk coefficient for non-smokers and a slightly higher relative risk coefficient for smokers. Thomas and colleagues (Th85), in their analysis of Colorado plateau uranium miners, found a relative risk model the most appropriate.

Relative risk coefficients decreased with increasing age at observation whereas attributable risk coefficients increased until the second oldest age group. A drop in relative and attributable risk coefficients after age 70 has been reported for both the Swedish iron ore and Saskatchewan uranium miners studies (8,12).

3.5 LIFETIME RISK ESTIMATES

The relative risk coefficient for the cohort (0.9 per cent per working level month) suggests that the dose required to double the risk of dying of lung cancer is 112 working level months. This could be achieved under present standards (four working level months per year) if a miner worked for 28 years. Thomas and McNeill (Th82) estimated the doubling dose to be 44 working level months based on analysis of the combined results of several studies; an estimate of 28 working level months can be derived from the analysis of Radford and St. Clair Renard (Ra84) of the Swedish iron ore miners.

Using the risk coefficients from the present study, a miner exposed for 30 years at four working level months per year from age 20 has a risk of 7,366 per 100,000 of dying of lung cancer by age 70 using the relative risk model and a risk of 6,371 per 100,000 using the attributable risk model. This compares to 3,740 per 100,000 for a non-exposed male. Adoption of the proposal by the International Commission on Radiological Protection to raise occupational exposure limits for radon daughters from 4.0 to 4.8 working level months per year (In81) would result in a further 517 (attributable risk model) to 705 (relative risk model) lung cancer deaths per 100,000 miners using the above assumptions. Although risks to the average uranium miner are likely to be considerably lower (few miners are likely to be exposed for 30 years at maximum permissible levels), there appear to be no grounds for relaxation of present standards.

3.6 METHODOLOGIC CONSIDERATIONS

The method selected to analyse the fluorspar cohort was the modified life-table method. The main advantages of this method are its simplicity and low model dependency (Wh79). A disadvantage of the person-year approach is the need to categorize continuous exposure variables. This may cause a problem when the number of strata is large relative to the number of PYs and deaths. This meant, for example, that although dose was classified into 13 categories, analysis was restricted to seven. Most criticisms (Be83; Br83) of the modified life-table approach have centered around the use of an external control group which may not be truly comparable with the exposed group as far as socio-economic status and prevalence of cigarette smoking are concerned. In order to investigate this criticism, analysis was performed in the present study using both an internal and an external control group.

3.61 INTERNAL VERSUS EXTERNAL CONTROLS

The use of an internal control population should largely remove the "healthy worker effect" which commonly is a problem in analyzing occupational cohorts (We83). While it is conceivable that employees not healthy enough to work in the mines were assigned to surface work, surface workers were still healthy enough to be employed. It is likely that surface workers resembled underground workers to a greater extent than did the entire male population of Newfoundland. Both surface and underground workers lived in the same locality; smoking levels were comparable However, no healthy worker effect was apparent among underground workers when using an external control group. Analysis from 1950 onward using the Monson (Mo74) computer program revealed a significant excess for both cancer and non-cancer mortality.

A further advantage of an internal control group is the potential of including in the analysis detailed auxiliary

variables such as cigarette smoking, which are usually not available for an external control group. In theory, another advantage in the present study was the ability to examine the cohort from 1933 onward; this would not have been possible using an external control group because age - sex - and cause - specific mortality rates were not available for Newfoundland as a whole prior to 1950.

However in practice, pre-1950 data had its problems. Prior to 1950, many small towns in Newfoundland such as St. Lawrence did not have resident physicians. Death certificates, called "returns of death", were often signed by the local clergyman. As such, the cause of death was often vague or anecdotal in nature. Often all the information available concerning an individual's death was recorded on a single line in the local church parish roll book. The quality of personal identifiers was consequently poor, making it difficult to link occupational records to death records. As well, the quality of the diagnosis of the cause of death is highly suspect in many instances.

Perhaps as a result of this, only a single lung cancer death was recorded prior to 1950. Even granting upwards of a twenty year latency for lung cancer and although the mines only opened in 1933, one would still have anticipated lung cancer deaths prior to 1950 in a cohort of this size from cigarette smoking alone. Possibly, deaths recorded as tuberculosis or other respiratory ailments were in some cases actually from lung cancer (de64). It was for these reasons that analysis was restricted to 1950-1984 instead of 1933-1984.

The analyses using surface workers as a control group examined only lung cancer and gastro-intestinal cancer mortality. The number of deaths in the control group was small; for some causes of death, such as pneumoconioses, all cases occurred among the exposed group. As such it was impossible to calculate

expected numbers for some causes of death using the mortality experience of surface workers. As well, the chi-square test, unlike the Poisson ratio test, does not assume a zero variance in the calculation of expected" numbers of deaths. As such, it may be less sensitive at detecting a real excess in mortality than is the Poisson ratio test, used with an external control group.

The high prevalence of smoking among underground miners compared to the external control population (Wh80; Jo85) should have resulted in an artifactual increase in SMRs for smoking-related cancers when external controls were used. However, cigarette smoking alone cannot account for the strong dose-response relationship found between radon daughter exposure and lung cancer mortality. The relationship remained even after stratification by smoking status.

The main advantage in using an external control group is the stability which it gives to the calculation of expected numbers of deaths. This in turn allows the study of rarer causes of death. Major disadvantages include the inability to control for the "healthy worker effect", the inability to analyse data before 1950, questionable comparability between the exposed and control groups and an inability to control for confounding variables such as cigarette smoking.

There is a trade-off between bias and the size of the standard errors in the "expected" numbers of deaths when using internal and external control groups. There is less bias in using an internal control, but the "expected" numbers of deaths have larger standard errors; the converse is true when using an external control group.

TABLE 3.1

PREVALENCE OF CIGARETTE SMOKING AMONG THOSE OF KNOWN* SMOKING STATUS UNDERGROUND VERSUS SURFACE WORKERS, BY PERCENTAGE

Smoking status	Underground	Surface
Never Smoked	13.3	11.4
Ex-Smoker	16.5	25.7
« 20 per Day	18.1	11.4
20+ per Day	52.0	51.4
Current Smoker	70.1	62.9

* Smoking status was unknown for 51.8% of underground miners and 90.0% of surface workers.

TABLE 3.2

LUNG CANCER: MEAN LATENCY (YEARS) BY AGE FIRST EXPOSED AND CIGARETTE SMOKING STATUS (NUMBER OF CASES) 1950-1984

Age first exposed (Years)	Smoking status Never	Ever	Unknown	Total
15-19	- (0)	30.6 (24)	32.0 (1)	30.6 (25)
20-29	22.0 (1)	26.5 (36)	26.8 (5)	26.4 (42)
30-39	17.0 (3)	28.9 (17)	24.0 (5)	26.5 (25)
40+	15.7 (3)	16.8 (6)	21.0 (9)	19.0 (21)
TOTAL	17.1 (7)	27.5 (83)	23.6 (23)	26.0 (113)

TABLE 3.3

LUNG CANCER MORTALITY* BY CUMULATIVE RADIATION EXPOSURE, FLUORSPAR MINER COHORT, NEWFOUNDLAND, 1950-1984 USING INTERNAL CONTROLS

Cumulative dose (WLM)	Mean dose (WLM)	Person-years	OBS	EXP**	SMR	95% CL LL	95% CL UL
0.0	0.0	9,051.0	6	6.00	1.00	-	-
» 0.0 - «100.0	21.8	13,715.0	16	8.04	1.99	0.39	10.17
100.0 - «400.0	229.4	6,979.5	12	5.53	2.17	0.81	5.84
400.0 -«1,000.0	607.3	4,281.0	14	3.25	4.31	1.23	15.08
1,000.0-«1,600.0	1284.2	1,733.5	14	1.20	11.63	4.70	28.77
1,600.0-«2,500.0	1964.8	1,579.0	25	1.04	24.05	11.96	48.39
2,500.0+	3449.1	1,169.5	29	0.79	36.68	18.92	71.13

OBS = observed number of deaths
EXP = expected number of deaths
WLM = working level month
LL = lower limit
UL = upper limit
CL = confidence limit

* The first 10 years of follow-up were excluded.

** Expected numbers of deaths based on age and period specific lung cancer mortality rates for the internal (unexposed) control group.

TABLE 3.4

LUNG CANCER MORTALITY* BY CUMULATIVE RADIATION DOSE, FLUORSPAR MINER COHORT, NEWFOUNDLAND, 1950-1984 USING EXTERNAL CONTROLS

Cumulative dose (WLM)	Mean dose (WLM)	Person-years	OBS	EXP**	SMR	95% CL LL	UL
0.0	0.0	9,051.0	6	6.69	0.90	0.33	1.95
» 0.0 - «100.0	21.8	13,715.0	16	9.10	1.76	1.01	2.86
100.0 - «400.0	229.4	6,979.5	12	5.62	2.14	1.10	3.73
400.0 -«1,000.0	607.3	4,281.0	14	3.18	4.41	2.41	7.39
1,000.0-«1,600.0	1284.2	1,733.5	14	1.24	11.32	6.19	18.99
1,600.0-«2,500.0	1964.8	1,579.0	25	1.04	23.97	15.51	35.38
2,500.0+	3449.1	1,169.5	29	0.86	33.55	22.47	48.18

OBS = observed number of deaths
EXP = expected number of deaths
WLM = working level month
LL = lower limit
UL = upper limit
CL = confidence limit

* The first 10 years of follow-up were excluded.

** Expected numbers of deaths based on age and period specific mortality rates for Newfoundland males for the period 1950-1984.

TABLE 3.5

LUNG CANCER MORTALITY BY TIME SINCE FIRST EXPOSURE AND CUMULATIVE DOSE, UNDERGROUND FLUORSPAR MINER COHORT, NEWFOUNDLAND, 1950-1984 USING EXTERNAL CONTROLS

Cumulative dose (WLM)	Time since first exposure (Years)	Person-years	OBS	EXP*	SMR	95% CL LL	95% CL UL
» 0.0 - « 100.0	0 - 4	4,291.0	0	0.34	0.0	0.00	10.90
	5 - 9	4,836.0	3	0.71	4.20	0.87	12.28
	10 - 14	4,596.0	4	1.12	3.57	0.97	9.14
	15 - 19	3,425.5	3	1.50	2.00	0.41	5.84
	20 - 24	2,313.0	2	1.47	1.36	0.17	4.91
	25 - 29	1,387.5	2	1.26	1.59	0.19	5.74
	30+	1,993.0	5	3.69	1.36	0.44	3.16
100.0 - « 1,000.0	0 - 4	633.0	0	0.03	0.0	0.00	140.74
	5 - 9	1,463.5	0	0.14	0.0	0.00	26.73
	10 - 14	2,119.0	4	0.31	13.00	3.54	33.30
	15 - 19	2,188.0	4	0.59	6.75	1.84	17.27
	20 - 24	2,058.0	2	0.97	2.07	0.25	7.48
	25 - 29	1,906.5	6	1.54	3.90	1.43	8.49
	30+	2,989.0	10	5.36	1.89	0.90	3.43
1,000.0+	0 - 4	3.0	0	0.00	0.0	0.00	-
	5 - 9	202.5	0	0.01	0.0	0.00	336.38
	10 - 14	613.0	1	0.06	0.0	0.39	86.44
	15 - 19	961.5	8	0.18	44.85	19.37	88.38
	20 - 24	850.5	18	0.28	67.08	38.57	102.85
	25 - 29	705.0	13	0.41	31.68	16.87	54.17
	30+	1352.0	28	2.20	12.72	8.45	18.38

OBS = observed number of deaths
WLM = working level month
EXP = expected number of deaths
CL = confidence limit
LL = lower limit
UL = upper limit

* Expected numbers of deaths based on age and period specific mortality rates for Newfoundland males for the period 1950-1984.

TABLE 3.6

LUNG CANCER MORTALITY* BY TIME SINCE LAST EXPOSURE AND CUMULATIVE DOSE, UNDERGROUND FLUORSPAR MINER COHORT, NEWFOUNDLAND, 1950-1984 USING EXTERNAL CONTROLS

Cumulative dose (WLM)	Time since last exposure (Years)	Person-years	OBS	EXP**	SMR	95% CL LL	95% CL UL
» 0.0 - « 100.0	0 - 4	1,812.5	1	3.02	3.02	0.08	16.84
	5 - 9	2,058.0	2	0.63	3.15	0.38	11.39
	10 - 14	3,501.0	5	1.32	3.79	1.23	8.84
	15 - 19	2,430.0	0	1.53	0.00	0.00	2.41
	20 - 24	1,657.5	2	1.43	1.40	0.17	5.06
	25+	2,256.0	6	3.80	1.58	0.58	3.40
100.0 - « 1,000.0	0 - 4	2,869.0	7	0.70	10.07	4.05	20.75
	5 - 9	1,544.0	3	0.77	3.91	0.81	11.43
	10 - 14	1,840.0	5	0.97	5.18	1.68	12.09
	15 - 19	1,565.5	5	1.18	4.25	1.38	9.91
	20 - 24	1,318.5	1	1.36	0.74	0.02	4.11
	25+	2,123.5	5	3.80	1.32	0.42	3.02
1,000.0+	0 - 4	2,348.5	31	0.62	50.28	34.17	71.34
	5 - 9	692.5	13	0.43	29.92	15.93	51.17
	10 - 14	540.0	13	0.51	25.34	13.49	43.33
	15 - 19	390.5	8	0.49	16.21	7.00	31.94
	20 - 24	286.0	0	0.54	0.00	0.00	6.82
	25+	224.5	3	0.53	5.66	1.14	15.94

OBS = observed number of deaths
WLM = working level month
EXP = expected number of deaths
CL = confidence limit
LL = lower limit
UL = upper limit

* The first 10 years of follow-up were excluded.

** Expected numbers of deaths based on age and period specific mortality rates for Newfoundland males for the period 1950-1984.

TABLE 3.7

LUNG CANCER MORTALITY* AMONG THE FLUORSPAR MINER COHORT, RISK** BY AGE AT FIRST EXPOSURE, NEWFOUNDLAND, 1950-1984 USING EXTERNAL CONTROLS (95% CONFIDENCE LIMITS)

Age at first exposure	Person-years at risk	Lung cancer deaths	Relative risk coefficients ($\times 10^2$)	Attributable risk coefficients ($\times 10^6$)
15-19	7,368.0	25	1.2 (0.8, 1.8)	5.2 (3.2, 8.3)
20-29	13,444.0	42	0.9 (0.6, 1.3)	6.1 (4.4, 8.5)
30+	8,645.5	43	0.8 (0.5, 1.4)	8.0 (4.6, 13.9)

* The first 10 years of follow-up after first exposure were excluded. The referent group was the Newfoundland male population (1950-1984).

** Risk estimates were based on an analysis which included unexposed workers, controlled for age. Note that person-years and deaths in this Table are only for exposed miners.

TABLE 3.8

LUNG CANCER MORTALITY* AMONG THE FLUORSPAR MINER COHORT, RISK BY AGE AT OBSERVATION, NEWFOUNDLAND, 1950-1984, USING EXTERNAL CONTROLS (95% CONFIDENCE LIMITS)

Age at observation	Person-years at risk	Lung cancer cases	Relative risk coefficients ($\times 10^2$)	Attributable risk coefficients ($\times 10^6$)
25-39	10,769.5	7	5.9 (2.7, 13.0)	2.9 (1.4, 6.2)
40-49	10,773.0	28	2.7 (1.6, 4.7)	6.3 (3.8, 10.5)
50-59	8,693.5	45	1.2 (0.7, 2.2)	10.1 (6.0, 17.1)
60-69	5,308.5	26	0.5 (0.3, 0.9)	9.5 (5.8, 15.7)
70+	1,752.5	10	0.3 (0.1, 1.0)	6.1 (1.8, 21.1)

* The first 10 years of follow-up after first exposure were excluded. The referent group was the Newfoundland male population (1950-1984).

TABLE 3.9

LUNG CANCER MORTALITY* AMONG THE NEWFOUNDLAND FLUORSPAR MINER COHORT, RISK BY CIGARETTE SMOKING STATUS USING EXTERNAL CONTROLS (95% CONFIDENCE LIMITS)

Cigarette smoking status	Person-years at risk	Lung cancer cases	Relative risk coefficients ($\times 10^2$)	Attributable risk coefficients ($\times 10^6$)
Never smoker	1,581.0	7	0.7 (0.0, 1.3)	7.6 (1.1, 14.1)
Ex-smoker	3,115.0	17	1.0 (0.3, 1.7)	6.2 (2.0, 10.5)
Current Smoker	10,652.0	57	0.9 (0.6, 1.3)	6.2 (4.3, 8.4)
Unknown	23,160.5	35	0.6 (0.1, 1.1)	5.4 (1.1, 9.6)
All miners	38,508.5	116	0.9 (0.6, 1.2)	6.3 (4.7, 8.3)

* The first 10 years of follow-up after first exposure were excluded. The referent group was the Newfoundland male population (1950-1984).

Figure 3.1

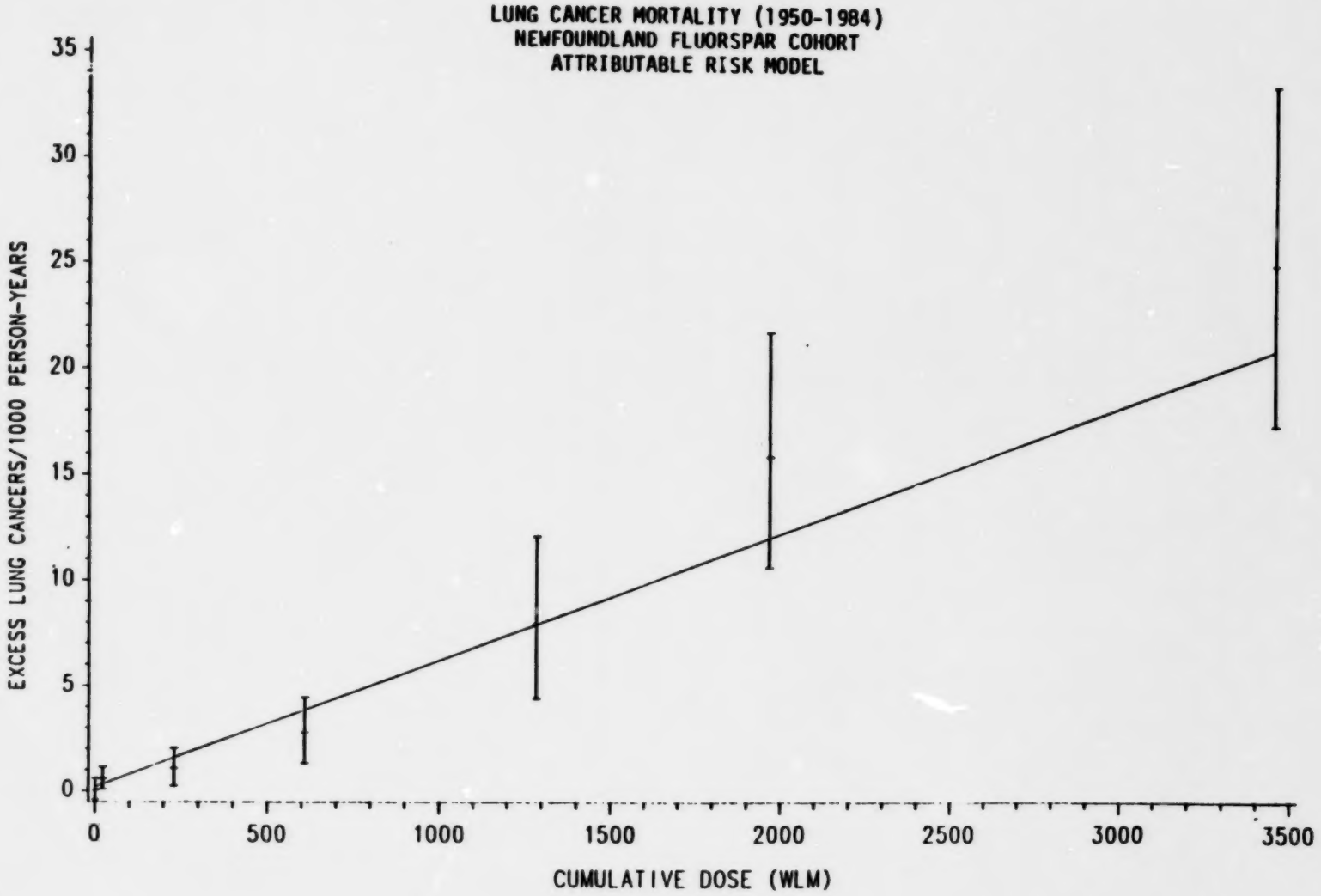
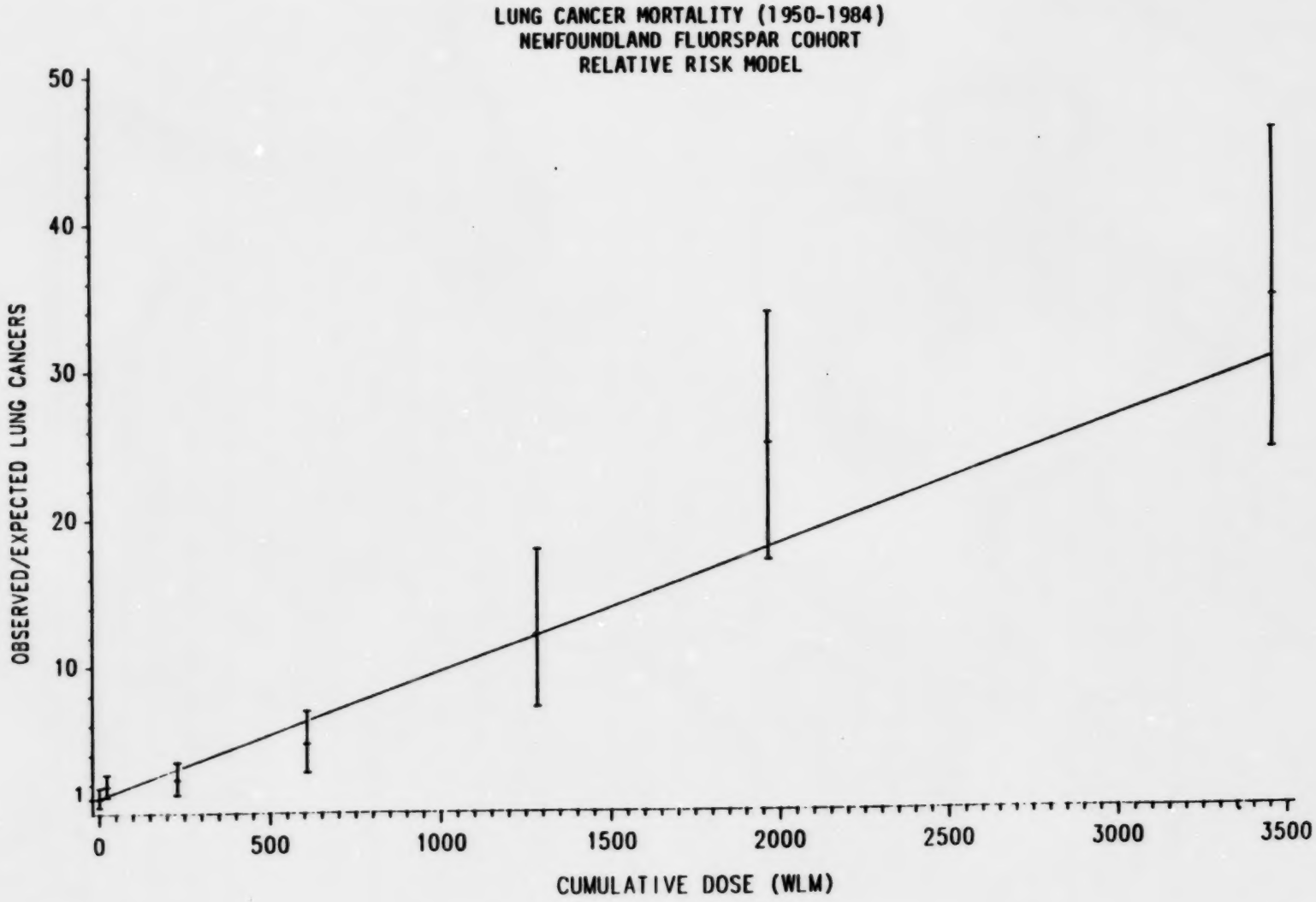

LUNG CANCER MORTALITY (1950-1984)
NEWFOUNDLAND FLUORSPAR COHORT
ATTRIBUTABLE RISK MODEL
EXCESS LUNG CANCERS/1000 PERSON-YEARS
0
5
10
15
20
25
30
35
0
500
1000
1500
2000
2500
3000
3500
CUMULATIVE DOSE (WLM)

Figure 3.2


LUNG CANCER MORTALITY (1950-1984)
NEWFOUNDLAND FLUORSPAR COHORT
RELATIVE RISK MODEL
OBSERVED/EXPECTED LUNG CANCERS
50
40
30
20
10
1
0
500
1000
1500
2000
2500
3000
3500
CUMULATIVE DOSE (WLM)

CHAPTER 4
OTHER CAUSES OF DEATH

4.1 CANCER MORTALITY

Standardized cancer mortality ratios (SMR's) for underground miners and surface workers for the period 1950 to 1984 using the Monson program (Mo74) are displayed in Tables 4.1 and 4.2 respectively. Among underground workers, significantly elevated cancer SMR's included cancers of the lung, salivary glands and buccal cavity and pharynx. Sites which had SMR's over 2.5, but were not significantly elevated include tongue, mouth and pharynx as well as mouth separately. The overall SMR for all cancer sites combined was 2.16. Even after removing lung cancer, a non-significant 13 percent excess remained.

Among surface workers, no cancer site had significantly elevated SMR's. The overall SMR for cancer was a significantly low 0.58. The SMR for lung cancer was 0.88. As with the underground miners, an excess was noted for salivary gland cancer. However it was not statistically significantly elevated.

4.11 CANCERS OF THE BUCCAL CAVITY AND MOUTH, STOMACH AND DIGESTIVE TRACT

Because cancers of the buccal cavity and mouth, stomach and digestive tract were either significantly elevated among underground workers only, or had been reported as elevated in previous analyses of this cohort (de77), an analysis of their relationship with cumulative radiation was undertaken.

For stomach and digestive tract cancer, analyses were undertaken using both internal and external controls. Results from these analyses are found in Tables 4.3 through 4.6. The highest SMR's were usually found in the highest dose categories. However, tests for trend for digestive tract and stomach cancer were not statistically significant ($p \gg 0.05$). As well, using external controls, no excess was noted for cancer of the

digestive tract, although a small, non-significant excess was noted for stomach cancer.

None of the other studies of radiation exposed mining populations has found an excess risk of dying of digestive tract cancers. However, one study of radium dial painters (Po78) found a non-significant increase of cancer of the large intestine, although no dose-response relationship was apparent.

A statistically significant excess was noted for cancers of the buccal cavity and pharynx for the period 1950-1984 using external controls. At face value, this finding would appear to be biologically plausible; the buccal cavity should be exposed to alpha radiation just as the lungs are when a miner breathes. However, it is probable, given the physiology of the respiratory tract, that more radon daughters would end up in the lung than in the buccal cavity. Analysis of buccal cavity and pharynx cancer mortality using external controls, found in Table 4.7, provides evidence of this. All cases of buccal cavity and mouth cancer occurred among miners with cumulative WLM exposures of less than 400. The excess may be partially related to the somewhat higher prevalence of cigarette smoking among underground miners compared to the Newfoundland male population as a whole.

4.2 NON-CANCER MORTALITY

SMR's for underground miners and surface workers for the period 1950 to 1984 using the Monson program for non-cancer causes of death are found in Tables 4.8 and 4.9 respectively. Among underground miners, significantly elevated causes of death include infective and parasitic diseases, pneumoconioses, silicosis and all causes. Most of the excess deaths from infective and parasitic diseases resulted from tuberculosis. Exposure to radon daughters results in damage to pulmonary function (Ar64). A dose-response relationship has been noted

between exposure to radon daughters and deaths from non-malignant respiratory diseases (Ar76).

The SMR's for the two hard-rock mining related causes, pneumoconioses and silicosis, were in excess of 60.0. In the St. Lawrence mines, the fluorspar was found in granite, which is primarily silica. Deaths from accidental falls, which could be partially related to underground mining, were elevated, but not significantly so. Among surface workers, no individual cause of death was significantly elevated. The overall SMR for all non-cancer causes of death was a significantly low 0.68. As expected, no cases of pneumoconioses or silicosis were recorded among surface workers.

TABLE 4.1

UNDERGROUND NEWFOUNDLAND FLUORSPAR MINERS
STANDARDIZED MORTALITY RATIOs
CANCER MORTALITY, 1950-1984

Site of cancer	Observed	Expected	SMR
Tongue, mouth, pharynx	4	1.63	2.46
Salivary glands	2	0.20	9.78*
Mouth	1	0.37	2.70
Buccal cavity and pharynx	6	2.19	2.74*
Esophagus	2	2.40	0.83
Stomach	22	16.24	1.35
Large intestine	5	8.73	0.57
Rectum	1	3.03	0.33
Large intestine + rectum	6	11.76	0.51
Pancreas	6	4.28	1.40
Digestive tract	37	36.66	1.01
Trachea, bronchus, lung	113	21.51	5.25**
Prostate	7	4.31	1.63
Urinary tract	4	4.14	0.97
Brain, nervous system	3	2.20	1.37
Lymphoid	3	2.91	1.03
Leukemias	3	1.98	1.51
All cancer except lung	72	63.82	1.13
All cancer	185	85.33	2.17**

* $P < 0.05$ ** $P < 0.01$

Expected numbers of deaths based on age and period specific mortality rates for Newfoundland males for the period 1950- 1984.

TABLE 4.2

NEWFOUNDLAND FLUORSPAR SURFACE WORKERS (UNEXPOSED)
STANDARDIZED MORTALITY RATIO's
CANCER MORTALITY, 1950-1984

Site of cancer	Observed	Expected	SMR
Tongue, mouth, pharynx	0	0.62	0.00
Salivary glands	1	0.09	11.10
Mouth	0	0.18	0.00
Buccal cavity and pharynx	2	0.95	2.10
Esophagus	1	1.20	0.83
Stomach	8	7.60	1.05
Large intestine	1	3.71	0.27
Rectum	0	1.30	0.00
Large intestine + rectum	1	5.01	0.20
Pancreas	1	1.80	0.55
Digestive tract	11	16.52	0.67
Trachea, bronchus, lung	6	6.57	0.91
Prostate	0	2.69	0.00
Urinary tract	1	1.84	0.54
Brain, nervous system	0	0.52	0.00
Lymphoid	0	0.93	0.00
Leukemias	0	0.70	0.00
All cancer except lung	14	27.82	0.50*
All cancer	20	34.39	0.58*

* $P < 0.05$ ** $P < 0.01$

Expected numbers of deaths based on age and period specific mortality rates for Newfoundland males for the period 1950-1984.

TABLE 4.3

STOMACH CANCER MORTALITY AMONG THE NEWFOUNDLAND FLUORSPAR MINER COHORT BY CUMULATIVE RADIATION EXPOSURE USING INTERNAL CONTROLS, 1950-1984

Cumulative dose (WLM)	Mean dose (WLM)	Person-years	OBS	EXP*	SMR	95% CL LL	95% CL UL
0.0	0.0	9,051.0	8	8.00	1.00	-	-
» 0.0 - «100.0	21.8	13,715.0	14	5.28	2.65	0.68	10.32
100.0 - «400.0	229.4	6,979.5	3	4.48	0.67	0.04	12.90
400.0 -«1,000.0	607.3	4,281.0	1	1.82	0.55	0.00	-
1,000.0-«1,600.0	1284.2	1,733.5	0	0.75	0.00	0.00	-
1,600.0-«2,500.0	1964.8	1,579.0	3	0.65	4.62	0.38	55.73
2,500.0+	3449.1	1,169.5	1	1.00	0.99		

OBS = observed number of deaths
EXP = expected number of deaths
WLM = working level month
\- = confidence limit » 100.0

LL = lower limit
UL = upper limit
CL = confidence limit

* Expected numbers of deaths based on age and period specific stomach cancer mortality rates for the internal control group for the period 1950-1984.

TABLE 4.4

STOMACH CANCER MORTALITY AMONG THE NEWFOUNDLAND FLUORSPAR MINER COHORT BY CUMULATIVE RADIATION EXPOSURE USING EXTERNAL CONTROLS, 1950-1984

Cumulative dose (WLM)	Mean dose (WLM)	Person-years	OBS	EXP*	SMR	95% CL LL	95% CL UL
0.0	0.0	9,051.0	8	7.90	1.01	0.44	2.00
» 0.0 - «100.0	21.8	13,715.0	14	6.34	2.21	1.21	2.21
100.0 - «400.0	229.4	6,979.5	3	4.51	0.67	0.14	1.94
400.0 -«1,000.0	607.3	4,281.0	1	2.24	0.45	0.01	2.49
1,000.0-«1,600.0	1284.2	1,733.5	0	0.95	0.00	0.00	3.90
1,600.0-«2,500.0	1964.8	1,579.0	3	0.90	3.34	0.69	9.76
2,500.0+	3449.1	1,169.5	1	0.90	1.12	0.03	6.23

OBS = observed number of deaths
EXP = expected number of deaths
WLM = working level month
LL = lower limit
UL = upper limit
CL = confidence limit

* Expected numbers of deaths based on age and period specific mortality rates for Newfoundland males for the period 1950-1984.

TABLE 4.5

DIGESTIVE TRACT CANCER MORTALITY AMONG THE NEWFOUNDLAND FLUORSPAR MINER COHORT BY CUMULATIVE RADIATION EXPOSURE USING INTERNAL CONTROLS, 1950-1984

Cumulative dose (WLM)	Mean dose (WLM)	Person-years	OBS	EXP*	SMR	95% CL LL	95% CL UL
0.0	0.0	9,051.0	11	11.0	1.00	-	-
» 0.0 - «100.0	21.8	13,715.0	21	14.68	1.43	0.94	2.19
100.0 - «400.0	229.4	6,979.5	5	7.30	0.69	0.13	3.61
400.0 -«1,000.0	607.3	4,281.0	3	2.86	1.05	0.61	1.80
1,000.0-«1,600.0	1284.2	1,733.5	1	1.07	0.94	0.69	1.27
1,600.0-«2,500.0	1964.8	1,579.0	3	0.90	3.35	0.26	43.57
2,500.0+	3449.1	1,169.5	3	1.26	2.38	0.21	27.34

OBS = observed number of deaths
EXP = expected number of deaths
WLM = working level month
LL = lower limit
UL = upper limit
CL = confidence limit

* Expected numbers of deaths based on age and period specific mortality rates for internal controls for the period 1950-1984.

TABLE 4.6

DIGESTIVE TRACT CANCER MORTALITY AMONG THE NEWFOUNDLAND FLUORSPAR MINERS COHORT BY CUMULATIVE RADIATION EXPOSURE USING EXTERNAL CONTROLS, 1950-1984

Cumulative dose (WLM)	Mean dose (WLM)	Person-years	OBS	EXP*	SMR	95% CL LL	95% CL UL
0.0	0.0	9,051.0	11	16.98	0.65	0.32	1.16
» 0.0 - «100.0	21.8	13,715.0	21	14.79	1.42	0.88	2.17
100.0 - «400.0	229.4	6,979.5	5	10.19	0.49	0.16	1.15
400.0 -«1,000.0	607.3	4,281.0	3	5.04	0.60	0.12	1.74
1,000.0-«1,600.0	1284.2	1,733.5	1	2.09	0.48	0.01	2.67
1,600.0-«2,500.0	1964.8	1,579.0	3	1.94	1.54	0.32	4.51
2,500.0+	3449.1	1,169.5	3	1.92	1.57	0.32	4.57

OBS = observed number of deaths
EXP = expected number of deaths
WLM = working level month
LL = lower limit
UL = upper limit
CL = confidence limit

* Expected numbers of deaths based on age and period specific mortality rates for Newfoundland males for the period 1950-1984.

TABLE 4.7

BUCCAL CAVITY AND PHARYNX CANCER MORTALITY BY CUMULATIVE RADIATION EXPOSURE USING EXTERNAL CONTROLS, NEWFOUNDLAND FLUORSPAR COHORT, 1950-1984

Cumulative dose (WLM)	Mean dose (WLM)	Person-years	OBS	EXP*	SMR	95% CL LL	95% CL UL
0.0	0.0	9,051.0	2	0.97	2.06	0.25	7.43
» 0.0 - «100.0	21.8	13,715.0	4	0.87	4.63	1.26	11.85
100.0 - «400.0	229.4	6,979.5	2	0.58	3.42	0.41	12.36
400.0 -«1,000.0	607.3	4,281.0	0	0.30	0.0	0.0	12.49
1,000.0-«1,600.0	1284.2	1,733.5	0	0.12	0.0	0.0	30.00
1,600.0-«2,500.0	1964.8	1,579.0	0	0.12	0.0	0.0	31.38
2,500.0+	3449.1	1,169.5	0	0.11	0.0	0.0	34.83

OBS = observed number of deaths
EXP = expected number of deaths
WLM = working level month
LL = lower limit
UL = upper limit
CL = confidence limit

* Expected numbers of deaths based on age and period specific mortality rates for Newfoundland males for the period 1950-1984.

TABLE 4.8

UNDERGROUND NEWFOUNDLAND FLUORSPAR MINERS, STANDARDIZED MORTALITY RATIOS NON-CANCER MORTALITY, 1950-1984

Cause of death	Observed	Expected	SMR
Infective + parasitic	16	7.94	2.01*
Ischemic heart disease	112	111.82	1.00
Cerebrovascular disease	11	33.81	0.33
Chronic obstructive lung disease	15	9.40	1.60
Pneumoconioses	7	0.13	51.86**
Silicosis	6	0.09	64.00**
Cirrhosis of the liver	2	3.57	0.56
Kidney disease	1	4.83	0.21
Motor vehicle traffic accidents	11	9.53	1.15
Accidental falls	5	2.31	2.17
Drowning	7	3.33	2.10
Suicide	2	4.23	0.47
Accidents/poisonings/violence	43	33.75	1.27
All causes	445	369.86	1.20**

* $P < 0.05$ ** $P < 0.01$

Expected numbers of deaths based on age and period specific mortality rates for Newfoundland males for the period 1950-1984.

TABLE 4.9

NEWFOUNDLAND FLUORSPAR SURFACE WORKERS (UNEXPOSED)
STANDARDIZED MORTALITY RATIO's NON-CANCER MORTALITY, 1950-1984

Cause of death	Observed	Expected	SMR
Infective + parasitic	3	2.70	1.11
Ischemic heart disease	44	48.92	0.90
Cerebrovascular disease	17	22.04	0.77
Chronic obstructive lung disease	4	3.86	1.04
Pneumoconioses	0	0.06	0.00
Silicosis	0	0.04	0.00
Cirrhosis of the liver	0	0.92	0.00
Kidney disease	3	2.36	1.27
Motor vehicle traffic accidents	1	1.82	0.55
Accidental falls	1	1.08	0.92
Drowning	0	0.68	0.00
Suicide	1	0.87	1.14
Accidents/poisonings/violence	4	7.23	0.55
All causes	113	166.30	0.68**

* $P < 0.05$ ** $P < 0.01$

Expected numbers of deaths based on age and period specific mortality rates for Newfoundland males for the period 1950 - 1984.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

5.1 CONCLUSIONS

New dose estimates, supplied by the Atomic Energy Control Board were used to analyse the mortality experience of 2,124 fluorspar miners, millers and surface workers. Significant excesses were noted for cancers of the lung, buccal cavity and pharynx and salivary glands as well as for silicosis and pneumoconioses.

Length of latent period for lung cancer was found to be inversely associated with age at first exposure, with non-smokers having shorter latency periods.

The risk of lung cancer mortality was highly related to cumulative radon daughter exposure. Two different series of analyses were performed: one using internal controls and one using external controls. Results were similar using the two control groups, with slightly higher standardized mortality ratios obtained using external controls. Using the external control group, relative and attributable risk coefficients for lung cancer were estimated as 0.89% per WLM and 6.3 per million person-years per WLM respectively.

The attributable risk estimate was comparable to those estimated from the Ontario uranium mining and Colorado Plateau mining cohorts, but much lower than those estimated from the Czechoslovakian and Swedish Iron ore mining studies. Inaccuracies in estimating doses as well as different lengths of follow-up and methods probably account for the differences.

Relative risk coefficients were highest for those first exposed before age 20. Cigarette smokers had comparable relative and attributable risks to non-smokers. Relative risks fell

sharply with age at observation whereas attributable risks were lowest in the youngest and oldest age groups.

Using the risk coefficients from the present study, a miner exposed for 30 years at 4 WLM per year from age 20 has a risk of 7,366 per 100,000 of dying of lung cancer by age 70 using the relative risk model and a risk of 6,371 per 100,000 using the attributable risk model. This compares to 3,740 per 100,000 for a non-exposed male. Even at "average" exposure levels of 1.54 WLMs per year (the mean exposure for Rio Algom uranium miners in 1983 at Elliot Lake) (Wr85), thirty years of exposure would still result in 1,022 (attributable risk model) to 1,413 (relative risk model) more lung cancer deaths per 100,000 than in the general Canadian population.

5.2 RECOMMENDATIONS

Recommendations for further work include the following:

1. Drain the now flooded Iron Springs mine and measure radon daughter concentrations under varying ventilation conditions. The weakest part of this study, a problem which it shares with all other mining - radiation studies, is that some exposures are estimated. Measurement of radon daughter levels in Iron Springs would not change this, but it would increase the precision of the estimates.

2. Obtain, if possible, further smoking data to allow future analysis to take into account changes in smoking habits among miners since the last (1978) survey.

3. In 1990, extend the mortality follow-up to the end of 1989.

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APPENDIX A
WORK HISTORY FILES

OCCUPATIONAL HISTORIES

When the latest phase of this project was initiated in 1981, there were five data-files containing either occupational histories or radiation estimates: files A, B-C, D, E and E-updates. A further file named F was created in 1982. The files are as follows:

File A

This file was assembled by the Newfoundland Government. It consists of personal identifiers and estimates of both cumulative pre-1960 and year - by - year post-1960 radiation exposures. The estimates assumed a constant working level of 13.0 in the mines prior to 1960. Unlike all the other files this file did not provide mine site, hours worked or occupation. Because of the crudeness of the dose estimates it was the least valuable of any of the data sets.

File B-C

This is a combination file produced by the Atomic Energy Control Board. The dataset was compiled from a survey conducted by AECB in 1978. The main purpose of the survey was to obtain cigarette smoking information on miners. In addition, the survey asked for social insurance numbers and occupational histories. Its strength lies in its smoking data and social insurance numbers. The occupational histories, because they were obtained by survey many years after the fact were considered less valuable than those found on files D or E. They were also found to correlate poorly with the work histories found on other files and as a result were not used.

File E

This file was assembled by Dr. A de Villiers of the Department of National Health and Welfare. It is the most extensive of any of the files. Dr. de Villiers obtained access to census records to replace occupational records lost in a fire in 1936. Classification of occupation was by a fairly simple system. This is the most complete of any of the files, i.e. it contains large numbers of miners not found on any of the other files. However, it provides limited work history information. No smoking data were available.

File E-updates

This is a continuation of file E which gives radiation exposure estimates for the years 1968 and 1969 in working level months.

File F

This file was assembled from copies of work histories obtained from the Aluminum Company of Canada Limited, the owner of one of the local fluorspar companies. A small file, excluding as it did employees of the St. Lawrence Fluorspar Company, it was still useful in that it was possible to work from original records. In addition, the records contained information unavailable on other files such as place of birth and salary level by year and occupation.

APPENDIX B

CREATION OF SMOKING HISTORIES

There were four sources of smoking information available. One was the 1978 survey by the Atomic Energy Control Board (file B-C). The other three sources were surveys conducted in 1960, 1966 and 1970 by Dr. de Villiers of the Department of National Health and Welfare. In order to create a single smoking history for each miner (when possible), the following steps were undertaken:

1. Smoking Histories were coded, keypunched and verified.

2. Ounces of hand rolled tobacco were converted into an equivalent number of cigarettes using 28 cigarettes to the ounce.

3. Weekly consumption of tobacco was converted into daily consumption by dividing by 7.

4. Hand rolled cigarettes per day and cigarettes per day were combined into a single category.

5. A variable "mean number of cigarettes per day" was created by taking the average number of cigarettes by daily consumption from the 1960, 1966, 1970 Health and Welfare surveys and from file B-C.

6. Age at which a miner first started smoking cigarettes as recorded on the 1960, 1966, 1970 and 1978 surveys was used to create a new variable "year started smoking cigarettes" by adding the age at which a miner first started smoking to his birth date.

7. The information necessary to create the variable "year started smoking cigarettes" was potentially available from each of the four surveys. Accordingly, the following order were used in selecting which file to use in creating this variable: 1960 survey, 1966 survey, 1970 survey, 1978 survey.

8. A variable "smoking status" was created.

   0 = never smoked cigarettes
   1 = ex-cigarette smoker
   2 = light cigarette smoker (<20 per day)
   3 = heavy cigarette smoker (20 or more per day)
   9 = unknown

APPENDIX C

INTERNATIONAL CLASSIFICATION OF DISEASES (ICD-8) CODES USED

CANCER MORTALITY

Site or type of cancer	ICD-8 rubric
Tongue, mouth, pharynx	141, 143-149
Salivary gland	142
Mouth	143-145
Buccal cavity and pharynx	140-149
Esophagus	150
Stomach	151
Large intestine	153
Rectum	154
Large intestine + Rectum	153, 154
Pancreas	157
Digestive tract	150-159
Trachea, bronchus, lung	162, 163
Prostate	185
Urinary tract	188, 189
Brain, nervous system	191, 192
Lymphoid	200-203
Leukemias	204-207

NON-CANCER MORTALITY, INCLUDING ALL CAUSES

Cause of death	ICD-8 rubric
Infective + parasitic	001-139
Ischemic heart disease	410-414
Cerebrovascular disease	430-438
Chronic obstructive lung disease	490-493, 519.3
Pneumoconioses	010, 515, 516
Silicosis	515.0, 515.1
Cirrhosis of the liver	571
Kidney disease	580-593
Motor vehicle traffic accidents	810-819
Accidental falls	880-887
Drowning	910
Suicide	950-959
Accidents/poisonings/violence	E800-999
All causes	001-999

APPENDIX D

WORKING LEVEL ESTIMATES ACCORDING TO OCCUPATION AND MINE SITE

The Atomic Energy Control Board of Canada provided estimates of radiation levels in the various mines according to year, giving a high, medium and low range of radiation in working levels. In consultation with AECB, occupations were classified as low, medium, or high with regards to probable radon exposure. Working Levels were then assigned to all possible combinations of mines, occupations and years, and tables of these values coded, keypunched and verified. A computer program was written to convert the year/occupation/mine site information contained on the unified work histories to estimated working levels using the tables giving all possible mine/year/occupation combinations with the appropriate working level estimates. Conversion of occupation and mine site information to yield a working level estimate was only necessary for the years 1933 through 1960. After this time working levels and/or working level month estimates were available from files A through E.

ESTIMATING PERSONAL EXPOSURES

The next step was to convert working levels into personal exposures expressed in working level months (WLM). This was calculated by dividing the hours worked in a year by 170 to calculate working months. This value was then multiplied by the appropriate working level to yield working level months. In many cases, miners changed occupations or mine sites during a given year. Because of this it was necessary to merge WLM's for the same year for each individual miner to produce a single WLM estimate by year for each miner.

APPENDIX E

STEPS TAKEN TO MERGE OCCUPATIONAL HISTORIES

In 1981, when the latest phase of this project was initiated, Files A and B-C contained all the data they were ever to possess. File D lacked mine site data (which existed on the source paper documents but had never been keypunched), while files E and E-updates lacked the six digit miner ID number which appeared on all of the other files. File F existed only as photocopies of Alcan employment records.

In order to create a working file prior to the creation of an analytical file, the following steps were taken:

1. A unique Miner ID number was added when possible to each work history on file E. Matching was by name, birth date, and work history. The work histories of 14 miners which could not be matched with other records and which could not be considered unique were dropped.

2. Duplicate work histories were removed.

3. Mine site information was keypunched from source documents and added to file D.

4. File F was coded, keypunched and verified from source documents obtained from Mr. Harold Smith, a lawyer for the Aluminum Company of Canada.

5. Coding for occupation and mine site for files B-C, D and F was standardized.

MERGING OF WORK HISTORIES

There were four components to the working histories: year worked, occupation, mine site and hours worked. The last three needed to be unified so that for a given year only a single record giving hours worked, occupation and mine site existed. To do this rules were developed for merging work histories. This was a fairly elaborate and at times somewhat arbitrary procedure. The following steps were performed:

A. Calculation of hours on file D.

If there was a * in column 40 of file D, this indicated that the hours worked that followed were cumulative to the year worked as indicated in columns 41 and 42. If this was the case, then the total number of hours up to the year of the * record minus 1 was calculated for files A, B-C, E and F. If file E was

present and the hours on file E and file D were roughly in agreement (60 percent to 140 percent) then file E was accepted. Otherwise manual resolution was used. If file E was absent, the comparison was repeated, first with file F and, if it was absent, file B-C. The same rules of acceptance were applied. If in file D hours appeared for years before the * then manual resolution was used, as was the case when more than one * appeared in a work history.

B. Merging files D and E.

If the year listed was not on both files, then whichever file existed was accepted. If the hours listed on file D were «80 percent or »120 percent of E and if one of the files listed hours under 3,000 for a year and one over 3,000 for the same year, then the smaller of the two was accepted. Otherwise the conflict was manually resolved. If the hours listed on file D were within 20 percent of those recorded on file E then file D was accepted. File D was accepted preferentially over file E when they agreed because both occupation and mine site information were more complete on file D. If either mine site or occupation was missing from the record accepted for hours, then the value was inferred from the other record.

C. Adding file E updates.

The E-updates file contained radiation estimates for miners for the years 1968 and 1969. They needed to be compared to what was found on file D. To do this, file D, which contains hours worked and occupation for these two years, needed to have radiation estimates made. These were calculated by multiplying hours worked underground (occupation codes 3-6) by 0.3 and dividing by 170. This estimate of radiation exposure in working level months (assuming a working level of 0.3 and 170 working hours in a month) was then compared to the estimates in file E-updates. If the estimates were between 60 percent and 140 percent, then the value in file D was accepted. If it was not, then manual resolution was used.

D. Adding file A

File A contained a single value for pre-1960 exposure, estimated by the Newfoundland Government by multiplying working months by 13.0, the estimated working level in all mines. This value was ignored. The file also contained a single value for 1960 and onward, but indicated if there was any exposure for each year from 1960 onward. In order to use the 1960 onward data, total WLMs were calculated from 1960 onward from the merged D-E file. When the merged file recorded no WLMs for this period,

then file A was accepted. This meant dividing the total WLMs recorded by the number of years in which exposure was reported and proportionally allocating the WLMs accordingly. When the WLMs recorded in file A were between 80 percent and 120 percent of those recorded in the merged file D-E, then file A was rejected. When file A estimates were less than 80 percent or more than 120 percent of those recorded on the merged file, then manual resolution was used.

E. Adding file F

For pre-1960 exposure, file F was only accepted when the merged file recorded no hours for a given year while file F did. When the hours on file F were between 60 percent and 140 percent of the merged file, then file F was rejected. When the difference was greater than this, manual resolution was used. If any accepted records on the merged file recorded an unknown WLM and occupation was missing, and if only one occupation was listed on file F, the occupation was selected from file F. If more than one occupation was listed, the record was submitted to manual resolution.

F. Adding file B-C

For years in which the merged file did not record WLMs and in which occupation was blank, if only one occupation was listed on file B-C, then the occupation was selected from file B-C. If more than one occupation was listed, the record was submitted to manual resolution.

G. Simplifying mine codes

The next step was to simplify the existing records to remove duplicate codes. This involved simplifying the mine codes to a more manageable number (from a previous 74 possible sites or combinations to 24 possible sites). This was done by removing codes which were never used and duplicate codes. Occupation codes were reduced from 78 codes to six codes based on likely level of radiation exposure. Codes 3 through 6 corresponded to low, medium and high levels of exposure, while codes 1 and 2 corresponded to no exposure (surface worker) and very low exposure (millworker).

APPENDIX F

MERGING PERSONAL IDENTIFYING INFORMATION

Personal identifying information was available, in varying amounts, on all five of the work history files. In addition, personal identifying information was available on the four smoking surveys and from the social insurance number file.

Selection of Birth date.

The following criteria were used in selecting birth dates:

1. File F was selected if available.

2. If file F was unavailable, and if both files B-C and D were available and if they agreed, then file D was selected

3. If both files B-C and D were available but did not agree, and the difference was less than 4 years, then file D was selected

4. If files B-C and D were available, did not agree and differed by more than 3 years, and if file E was available and if the year of birth on file E was in agreement with either file B-C or D, then the file in agreement was selected.

5. If file E was unavailable, then a value midway between Files B-C and D was entered.

6. If file E was available but did not agree with either file D or E, then the average of the two closest years was selected.

7. If only one of files B-C and D was available, then it was selected.

8. If none of files F, B-C or D were available, and if file E was available then it was selected.

9. If birth date was unavailable from any of these files then date of birth was selected from the smoking file if present.

10. If unavailable from all of the above sources, birth date was selected from the social insurance file.

11. Individuals who lacked adequate personal identifying information (name and year of birth) were dropped at this stage. The result was the removal of 537 workers from the present analysis.

APPENDIX G

VALIDATION CHECK

Data created by the previous program was assessed for internal consistency and any data which failed this check were manually resolved. The following checks were made:

1.	Year of birth	none	«1860 or »1963.
2.	Month of birth	none	«01 or »12.
3.	Day of birth	none	«01 or »31.
4.	Smoking status	none	»9.
5.	No. of cigarettes/day	none	«01 or »99.
6.	Year started smoking	none	«1900 or »1978.
7.	Underlying cause of death	none	«001 or »999.
8.	Contributing cause of death	none	«001 or »999.
9.	Year of Death	none	«1933 or »1981.
10.	Month of Death	none	«01 or »12.
11.	Day of Death	none	«01 or »31.
12.	Age at Death	none	«15 or »105.
13.	Age first worked	none	«12 or »65.
14.	Age first exposed	none	«15 or »65.
15.	Age last exposed	none	«15 or »65.
16.	Age last worked	none	«15 or »75.
17.	Year worked	none	«1933 or »1978.
18.	Working Level Months	none	«0.0 or »960.

19. Year of Birth « year first worked ≤ Year first exposed (if exposed) ≤ Year last exposed ≤ Year last worked ≤ Year of death.